STIMULATORY EFFECTS OF RADIATION FROM A QUARTZ MERCURY VAPOR ARC UPON HIGHER PLANTS

HARRY J. FULLER

Assistant in Botany, Henry Shaw School of Botany of Washington University

Review of Past Work

The deleterious effects of ultra-violet radiation upon plants have been known since the work of Bailey ('94), who found that electric arc discharges caused the collapse and the loss of color of epidermal cells of *Coleus* plants. Since Bailey many other workers have studied the reactions of plants to ultra-violet radiation, in the majority of cases, that from an unscreened mercury vapor arc or an unscreened iron or carbon arc. Green ('97) found ultra-violet rays destructive to diastase in leaves. Hertel ('05) found a retardation of cyclosis and finally death in leaf cells of *Elodea*, and lethal effects on bacteria and other micro-organisms. Maquenne and Demoussy ('09) showed a killing and blackening effect of ultra-violet rays on plant epidermises. Schulze in the following year, studying the reactions of individual cells to the mercury arc radiation, found disorganization of cytoplasmic and nuclear structures and a repressive effect upon the germination of fungous spores. Stoklasa ('12) carried out lengthy investigations on many types of plants and found only lethal effects. Kluyver ('11) verified the work of Bailey and others and studied in addition the relative effects of ultra-violet rays on various individual organs and tissues of plants; he found the most marked injury in the shorter ultra-violet rays, those below 290 mμ and he failed to discover any resistance on the part of the plant to these rays. Chauchard and Mazoué ('11) found that ultra-violet radiations were destructive to many enzymes in vitro. Bovie ('16), investigating the effects of the Schumann region on both plants and animals, found a marked increase in lethal effects in direct proportion to decreasing wave length. Ursprung and Blum ('17) used deplasmolysis as an indicator of injury and found that the wave-lengths below 290 mμ caused the greatest damage, that the presence of some pigments evidently increases the absorptive capacity of cells for ultra-violet rays, but that chlorophyllous cells of the epidermis are more resistant than non-chlorophyllous ones.

Burge ('17), working on bacteria that liquefy gelatine, found that the rays injured the organisms not by destroying intracellular enzymes but rather by coagulating the protoplasm. In the next year, Schanz found that plants kept under Euphos glass, which screens out the ultra-violet spectrum, grew more rapidly and flowered earlier than plants which received even very small amounts of ultra-violet. Again Schanz ('19) found the maximum growth of plants in height occurred when the blue-violet portion of the spectrum was removed. Luers and Christoph ('23) studied further the injurious effects of ultra-violet upon yeasts, and in the same year Tanner and Ryder ('23) published results on similar experiments with yeasts; they found that the fermentative ability of the cells decreased in proportion to the length of radiation, that pigmented yeasts are more resistant to ultra-violet than colorless forms, and that there is evidently a relationship between cell size and the effects of radiation, since smaller yeast cells seemed more sensitive to injury than did larger ones. Coblentz and Fulton ('24) found that wave lengths extending from 365 mμ down through the Schumann region were bactericidal, the greater injury occurring in the shorter rays. Brooks ('26) studied the penetration of 2-, 6-dibromophenolindophenol into rayed cells of *Valonia* and found that the penetration of the dye was greater when the shorter waves were employed, which would seem to indicate that protoplasm loses its power of selective absorption under such treatment. Gibbs ('26), studying the effects of radiation from an unscreened mercury arc on *Spirogyra submaxima affinis* and *S. nitida affinis*, found that only rays of less than 3126 Ångstrom units appeared to be toxic. Russell and Russell ('27) rayed seedlings with an unscreened mercury arc and found that dwarfing resulted in direct proportion to the duration of exposure; they also found that the injurious effects were more marked in etiolated than in normal seedlings.

This is by no means all of the work which has been done upon the subject, but it is representative of the various aspects of the problem, and it illustrates all the toxic effects of ultra-violet radiation on plants, which may be summed up as follows:

1. Formative changes in the organism as a whole—e. g., the collapse of epidermal tissue, the burning off of hairs, the blackening of leaves, reduction in size of leaves, general dwarfing of the organism, etc.

2. Structural changes in the protoplasm: coagulation, bursting of cells, clumping of plastids, destruction of vacuoles, etc.

3. Changes in physiological processes: loss of selective absorption, cessation of cyclosis, aberrations of mitosis, destruction of enzymes, etc.

4. As the end result of the above-mentioned changes, the death of the organism.

That accelerative stimulation of plants can be brought about by ultra-violet radiation is another aspect of the subject which has received attention and which has proved extremely controversial in nature, in contrast to the subject of injurious effects. Numerous workers have reported varied types of stimulatory effects on both lower and higher plants—stimulated growth, increased production of food substances, of pigments, stimulated reproductive activity, etc.

Bonnier and Mangin ('86) reported a slight stimulatory effect of ultra-violet upon assimilatory processes in the plant. Tolomey ('94), using a magnesium light as a source of ultra-violet rays, found an increased formation of food substances in rayed plants. Grantz ('98) found that ultra-violet radiation caused an increase in the numbers of fruiting bodies produced by certain fungi. Laurent and Marchal ('03) reported that ultra-violet promoted the synthesis of proteins in plants. Stoklasa ('12) found that *Azotobacter* cultures, when rayed for very short periods—from 1 to 8 seconds—showed increased growth. Tsuji ('18) obtained increased growth and a higher percentage of sugar in sugar cane which was given weak doses of ultra-violet rays. Dufrenoy ('25) rayed zoospores of *Blephorospora* and *Phytophthora* and found that when the period of exposure was reduced to two minutes, the cilia were withdrawn within five minutes preparatory to germination, a process which normally requires several hours; when the dosage of ultra-violet was increased, only injury resulted. Euler ('25) obtained increased growth of the mycelium of *Penicillium glaucum* Link and *Rhizopus chinensis* Saïto by short exposures to an unscreened arc, and he asserted that there is a certain optimal period of radiation for organisms, above which only injury occurs.

Coward ('27) reported an accelerated formation of vitamin A in the tissues of wheat seedlings under the influence of ultra-violet radiation; he found that this effect occurred only when rays shorter than 3130 Ångstrom units were removed. Sheard and Higgins ('27) found the shorter ultra-violet wave lengths to be stimulatory to the germination of seeds of cucumber and the longer wave lengths effective in promoting later growth of the seedlings. They explain the inhibitory effects of the rays ranging from 270 mμ to 320 mμ as being caused by the action of these rays in coagulating the seed albumen. They also state that the lesser wave-lengths of light, especially those of the near or biologic ultra-violet, act as stimulative agents which modify the endogenous growth of the cells and of the organism, whereas the greater wave lengths of visible and infra-red rays influence the exogenous metabolic processes in the subsequent growth and development of the plant. Beeskow ('27) found that a ½-minute daily irradiation of soy-bean seedlings under an unscreened mercury vapor arc caused no injury and in some cases seemed to produce a slight stimulation to growth. Beeskow further discovered that rayed plants showed a slight increase in calcium and phosphorus content.

Nadson and Philippov ('28) reported that the longer ultra-violet rays stimulated the growth of several yeasts and mucors, while the shorter rays killed the organisms; in some of the fungi with which they worked, they found an increase in the numbers of reproductive organs produced, both asexual and sexual, under the influence of ultra-violet radiation. Stevens ('28) rayed cultures of *Coniothyrium* and *Glomerella* with a mercury vapor arc and found that the numbers of perithecia and pycnidia were greatly increased; in these fungi the reproductive organs are not normally produced until the cultures are very old, but under the influence of the ultra-violet radiation, they appeared almost immediately. This really cannot be considered as accelerative stimulation, since Klebs has shown that in many lower organisms, reproductive processes take place only when environmental conditions become suddenly unfavorable for vegetative growth. The subject is by no means settled, however, and will bear further investigation. Stevens found only lethal effects on spores and mycelium with the unscreened lamp; the rays instrumental in bringing about the production of reproductive organs were those shorter than 313 mμ.

Delf, Ritson and Westbrook ('27), using an unscreened mercury arc, found injurious effects on a variety of plants, but found that when seedlings of some of them were rayed for 30 seconds daily, a small amount of increased growth was obtained; the number of plants used was small, however, and hence the results cannot be considered as of great reliability. McCrea ('28–'29) found that plants of *Digitalis purpurea* which were grown under vita-glass, transmitting to 289 mμ, in a greenhouse through the seedling stage, showed an increased digitalin content of 21 to 40 per cent, although there was no perceptible increase in the amount of growth of the plants. Eltinge ('28) rayed plants with a mercury arc, screened and unscreened, and found in some cases that growth was apparently stimulated when screens were used; she used a screen of vita-glass and one of quartz-lite glass; the former transmits to 289 mμ, the latter to 313 mμ; plants rayed with the vita-glass showed for the most part better growth than those rayed with the quartz-lite; both showed more growth than the controls; when the unscreened lamp was used, only injury occurred. Shortly after this work, Popp and Brown ('28) reported on experiments with some of the plants with which Miss Eltinge had worked; they found only injury under an unscreened lamp; moreover, they found that when the lamp was screened to give wave lengths down to only 300 mμ, no stimulation occurred, nor was there any injury. Fulton and Coblentz ('29) found indications of stimulation on moulds which they exposed to the mercury arc for short periods; when the periods of exposure were increased, injury resulted.

Newell and Arthur ('29) rayed tomato plants with a mercury arc, both unscreened and screened with filters transmitting small progressive portions of the ultra-violet spectrum, and found only injury in the rays shorter than the solar limit; the upper limit at which harmful effects were produced was found to be at 281.1

mμ; in the longer wave lengths (above 290 mμ) there was neither injury nor stimulation. Sheard, Higgins, and Foster ('30) reported the results of experiments on the germination and early growth of seedlings under various portions of the solar spectrum; their results indicated that the ultra-violet and infra-red portions of sunlight are stimulatory to germination and enhance growth and later development, but that they induce less chlorophyll formation than do other portions of the spectrum.

Statement of the Problem and Criticisms of Previous Work

The object of this work is to determine whether or not radiation from a quartz mercury vapor air-cooled arc might cause definite accelerative stimulation in the growth of higher plants, in an endeavor to contribute something positive to the much-controverted subject. Certain criticisms of previous work may be offered which may be of aid in accounting for the discrepancies mentioned in the reviews. In the first place, most workers heretofore have neglected to furnish quantitative measurements of the radiant energy given off by the lamps with which they have worked; obviously differences in respect to this factor can be expected to account for a large portion of the disputed results. Secondly, accurate measurements of the wave lengths given off by the sources of radiation have been omitted in some cases; there can of course be no basis for the comparison of results obtained with a screened lamp transmitting to 300 mμ, with those obtained from an unscreened lamp which transmits, say, to 220 mμ, and yet very often attempts are made to correlate the findings of experiments conducted under such widely divergent conditions, with the result that endless and unnecessary disputes have arisen. In the third place, the methods of exposing the plants to the source of radiation have differed; some workers have rayed plants at a distance of 20 inches from the arc, still others at 100 inches, and so on; further, the periods of irradiation have varied widely, as well as the methods of applying them—some investigators have given the same dosage every day, others have increased the periods gradually throughout a series of daily irradiations, etc. In the last place, the experimental populations have in most cases been too small to make possible the exclusion of individual variation in interpreting the results; conclusions drawn from the reactions of six or eight plants cannot be of much value. This factor can be overcome only by the use of large numbers of individuals in the experiments; then, too, accurate statistical analyses have not been made of results, with the consequence that the reliability of measurements obtained has not been determined.

In the past, most workers have assumed the effects produced by the mercury and carbon and iron arcs to be due to the ultra-violet spectrum alone. It has been shown by Sheard and Higgins ('27) that the mercury vapor arc may give off as much as one third of its total radiation as infra-red. Hence, it is a flagrant disregarding of facts to assume that the effects of the mercury arc on organisms are due to the ultra-violet region alone. In this paper, the term "ultra-violet" is used to express this limitation—that is, to mean in reality, "the radiation from the mercury arc." In a continuation of the present work, the author intends to study the effects of the radiation from a lamp screened by a quartz water cell to remove the greater portion of the infra-red rays, upon the same plants used in this work.

In the prosecution of this work, an attempt has been made to reduce to a minimum the four objections raised in the second preceding paragraph.

Methods and Materials

The experimental methods used in this work were planned specifically in relation to three recent works on the subject of stimulation of plants by ultra-violet, that of Miss Eltinge ('28), of Popp and Brown ('28), and of Newell and Arthur ('29). Miss Eltinge reported that the radiation from a mercury arc, screened by vita-glass and quartz-lite, "was beneficial" to some of the plants with which she worked—*Cucumis sativus*, var. "Improved Green Hybrid," *Coleus Blumei*, *Bryophyllum pinnatum*, *Lactuca sativa*, and others. Popp and Brown, working on some of the same plants, reported only injurious effects with the unscreened lamp, and neither injury nor stimulation with the lamp screened to remove wave lengths below 300 mμ. Newell and Arthur likewise obtained only deleterious effects with the unscreened lamp in their work on tomatoes; above 281.1 mμ they found neither injury nor stimulation. It was thought that certain differences in the experimental procedures of Miss Eltinge and of these other investigators might account, in part at least, for the apparently conflicting results, and so the methods they employed were carefully compared in order to devise a technique which might incorporate certain aspects of the methods of all three investigators and which thus might offer some common basis for comparison.

The following differences were noted:

1. Miss Eltinge rayed the plants she used for periods which began with 30 seconds on the first day and which increased by that same amount on each successive day. Popp and Brown, and Newell and Arthur used a constant period for each daily irradiation; no incremental method was used. The periods used by them varied from a few seconds to several hours.

2. Miss Eltinge used the vita and quartz-lite glass screens in her work; Newell and Arthur, and Popp and Brown used filters whose transmissions differed from those used by Miss Eltinge and in addition used the unscreened arc in attempting to find whether or not stimulation occurred.

3. Miss Eltinge rayed her plants at distances of 50 and 100 inches. Popp and Brown used a distance of 50 centimeters, Newell and Arthur a distance of 15 inches.

The experimental work described in this paper was planned upon the basis of these differences in the following manner:

Since the methods of irradiation employed by Miss Eltinge differed from those of Popp and Brown and Newell and Arthur, it was thought that, by using Miss Eltinge's procedures, which she reported to cause stimulation, on the plants employed by these other workers and reported by them to be unstimulated, it might perhaps be possible to accelerate their growth. Accordingly, the plants selected were *Cucumis sativus* L., var. "Early White Spine," used by Popp and Brown, and *Lycopersicum esculentum* Mill., the common tomato, which Newell and Arthur employed in their work. In addition to Miss Eltinge's method of applying the irradiation periods—that of daily increments of 30 seconds—, experiments using equal daily exposure periods were performed to determine whether or not the incremental method might enable the plants to become adjusted to the radiation and thus to escape injury and perhaps even to derive some benefit from the gradually increased dosages. In order to make certain that any differences resulting from the two methods of dosage would be due only to the difference in the method and not to unequal quantities of energy received, the periods of exposure were planned so that at the end of the experiment the plants rayed according to the two procedures would have received exactly the same amount of radiant energy.

The source of ultra-violet radiation in these experiments was an air-cooled Uviarc quartz-mercury vapor arc from the Burdick Cabinet Co.; throughout the experiments the arc was used at 70 volts with a current of 6 amperes. In some of the work the lamp was unscreened, and in other portions the quartz-lite and vita-glass filters were used. Spectrographs showed that the unscreened lamp gave off radiation ranging from 578 mμ to 200 mμ; when the arc was screened with vita-glass, the ultra-violet spectrum below 289 mμ was removed; when the arc was covered with the quartz-lite filter, the rays below 313 mμ were removed.

In this work two experiments were performed, the first, a preliminary one, intended to "feel out" any tendencies which might become evident, the second, a more exhaustive investigation of the results obtained from the first. In the following discussion, these experiments will be designated as I and II respectively.

In experiment I, the plants were rayed at 50 inches for 4 weeks. The following experimental groups were used:

Set A—Controls.

Set B—Plants rayed, using a quartz-lite filter, for a period of 30 seconds on the first day, increased thereafter by an equal period daily.

Set C—Plants rayed, using a quartz-lite filter, for a period of 7.5 minutes daily.

Set D—Plants rayed with the unscreened arc, with radiation periods as in Set B.

Set E—Plants rayed with unscreened arc, the radiation periods as in Set C.

The groups in experiment I consisted of 15 plants each, a number probably too small to overcome the factor of natural variation in the final interpretation of results but nevertheless large enough to indicate general trends. The plants were rayed daily, with the periods adjusted to insure equal amounts of energy for the rayed groups. In this experiment the plants were grown individually in 2-inch pots, in a mixture of three-fourths loam and one-fourth sand. The plants were moved about in the greenhouse at the end of each week to insure similar environmental conditions.

In experiment II the plants were rayed at 100 inches for 5 weeks. The experiment consisted of the following groups:

Set A—Controls.

Set B—Plants rayed, using a quartz-lite filter, for a period of 30 seconds on the first day, increased thereafter by 30 seconds daily.

Set C—Plants rayed, using a quartz-lite filter, for a period of 9 minutes daily.

Set D—Plants rayed, using a vita-glass filter, with irradiation periods as in Set B.

Set E—Plants rayed, using a vita-glass filter, with irradiation periods as in Set C.

Each group in experiment II consisted of 100 plants, a number large enough to reduce to a minimum the factor of individual variation.

The heights and numbers of leaves in the plants in both experiments were recorded at the beginning of the experiments, at the end of half the period, and again at the conclusion. In addition, in experiment II, wet weights, dry weights, and ash weights were determined, and from these results the dry weight percentages of wet weight and the ash-weight percentages of dry weight were calculated. In the determination of dry weights, the plants were dried in an oven at 60° C. After the weighings had been completed, the plants were incinerated in porcelain crucibles in a Bunsen flame until the ash fused; the covered crucibles were then placed in a desiccator to cool, in order to exclude the possibility of error from the condensation of atmospheric water vapor upon the ash or crucible. Since the time was not available for making 1,000 individual ash determinations of the plants in experiment II, 30 plants were selected from the control set and 30 from the group which showed the greatest growth under the arc, 10 plants from among those which showed growth greater than that of the group average, 10 from those which showed growth equal to that of the group average, and 10 from those which showed less growth than the group average.

Intensity measurements were made by means of a Leeds and Northrup high sensitivity type P reflecting galvanometer #2239, with a sensitivity of .7 microamperes, and two Cenco linear thermopiles. A carbon filament incandescent lamp, from the Bureau of Standards of the U. S. Department of Commerce, standardized to give a radiation of 86.2×10^{-8} watts per square millimeter of receiving surface at two meters when lighted at .4 amperes and 99.5 volts, was used as a basis for computing the radiant energy given off by the arc. The intensity measurements are as follows:

At 100 inches:

Unscreened arc—956.44×10^{-8} watts per sq. mm.
Vita-glass —732.70×10^{-8} watts per sq. mm.
Quartz-lite —724.08×10^{-8} watts per sq. mm.

At 50 inches:

Unscreened arc—3825.76×10^{-8} watts per sq. mm.
Vita-glass —2930.80×10^{-8} watts per sq. mm.
Quartz-lite —2896.32×10^{-8} watts per sq. mm.

Observations and Results

EXPERIMENT I

Cucumbers.—The first visible effects on rayed plants appeared in set E, rayed 7.5 minutes daily with the unscreened arc, at the end of a week's period of irradiation. The upper epidermis appeared shiny and there was a slight curling of the younger leaves. Upon examination with a hand lens, it was found that the hairs on the upper epidermis had been completely burned off. These effects rapidly became intensified; after about 12 days the enlargement of young leaves had ceased entirely and all of the leaves of the plant were badly curled. The leaves were stiff and brittle, and showed a slight brownish discoloration of the upper surfaces. At the end of 22 days the plants had practically ceased growing, and death followed a few days later.

In set D, rayed for incremental periods with the unscreened arc, the first manifestations of injury were not as pronounced as those in set E. The first effects of burning became noticeable on about the twelfth day and became gradually more intense, culminating in death on about the twenty-eighth day. At the time of death, the leaves were somewhat larger and more numerous than those in set E and the plants were somewhat taller. The growth differences are shown in table I at the end of this section.

There were no striking differences between sets A, controls, and B, rayed with the quartz-lite filter for incremental periods, at any time during the experiment, except that some plants in set B were slightly taller than those in set A. Since 9 of the 15 plants in set B were taller than the tallest plants in set A, it seemed that some small amount of stimulation of growth had occurred in set B, but, as has been stated before, the number of plants was not large enough to overcome individual variation. Hence, no definite interpretation can be placed upon the results. The number of leaves in set B was slightly greater than that in set A.

Set C, rayed 7.5 minutes daily with the quartz-lite filter, showed a perceptibly slower rate of growth and a smaller number of leaves than set B. Aside from this, there were no differences between the two sets. Neither showed any injury whatsoever, and the leaf sizes were approximately equal.

It will be seen from the figures in table I that the growth rate in set A during the first two weeks was slightly less than that occurring during the last two weeks of the experiment. In set B the same relationship held, but in set C the growth rate through the last two weeks was less than that of the first two weeks; this condition prevailed in sets D and E also. It is interesting to note that these growth relations were practically identical in the tomato plants.

Tomatoes.—The various experimental groups of tomatoes stood in approximately the same relation to each other as did the cucumber groups. Sets D and E showed the same type of injury as did the cucumbers—burning off of epidermal hairs, discoloration of epidermal tissue, the final cessation of growth, and the death of the plant. The tomatoes seemed slightly more sensitive in their reaction to the unscreened arc than did the cucumbers, for they exhibited signs of injury after about 6 days of irradiation. They ceased growing at about the same time as did the cucumbers, but they remained alive a few days longer. The injurious effects were less pronounced in set D than in set E, as was also the case in the cucumbers.

The plants in set B showed a slightly increased amount of growth over the controls, and those in set C showed less growth than did set B. Aside from this, there were no differences in the plants in these groups. The growth rates in sets A and B were greater during the last two weeks of the period than during the first two; in sets C, D, and E, the reverse occurred. The similarity of these reactions in both cucumbers and tomatoes seemed to indicate a tendency—that of the repression of growth by ultra-violet radiation when the dosage exceeds an optimum value. This will be discussed later in the paper.

Plate 3, fig. 1, shows the appearance of plants from the five sets of tomatoes at the end of the four weeks of exposure.

TABLE I

CUCUMBERS

Set	Average increase in height of plant and in number of leaves during experiment					
	1st 2 weeks		2nd 2 weeks		4 weeks—total	
	Height	Leaves	Height	Leaves	Height	Leaves
	cm.		cm.		cm.	
A	4.71	2.85	4.92	1.00	9.63	3.85
B	4.64	2.57	5.30	2.21	9.94	4.87
C	4.23	2.57	3.44	1.33	7.67	3.80
D	4.02	2.06	.94	.71	4.96	2.77
E	3.05	2.01	.17	0.00	3.22	2.01

TABLE II

TOMATOES

Set	Average increase in height of plant and in number of leaves during experiment					
	1st 2 weeks		2nd 2 weeks		4 weeks—total	
	Height	Leaves	Height	Leaves	Height	Leaves
	cm.		cm.		cm.	
A	3.99	1.20	6.33	2.00	10.32	3.20
B	4.76	1.87	6.27	1.22	11.03	3.09
C	3.86	2.00	3.20	1.30	7.06	3.30
D	3.02	1.28	1.82	.54	4.84	1.82
E	2.44	1.25	1.25	.40	3.69	1.65

EXPERIMENT II

When indications of stimulation were found in the plants of experiment I, rayed through the quartz-lite filter, it was decided to perform another experiment to study further these stimulatory effects and in addition to study with the aid of the vita-glass filter the effects of the rays between 313 mμ (the quartz-lite limit) and 289 mμ. To overcome errors due to natural variation, the number of plants in each group was increased to 100; the plants were grown in large-sized greenhouse flats, 25 in a flat, in the same soil as was used for experiment I. The following were the experimental groups:

Set A—Controls.

Set B—Quartz-lite filter; rayed 30 seconds the first day and 30 seconds additional on each following day.

Set C—Same as set B, but rayed 9 minutes daily.

Set D—Vita-glass filter; rayed as in set B.

Set E—Vita-glass filter; rayed as in set C.

The experiment was carried through 5 weeks; the plants were rayed at 100 inches. Statistical analyses were made of the results of experiment II to determine their reliability.

Cucumbers.—The growth increases and the various weights are shown in tables IIIa and IIIb. The plants at the beginning of the experiment averaged about 5 cm. in height.

As the figures show, there was not much difference among sets A, B, C, and D, as to growth rate and number of leaves produced. In set E, however, the increase in elongation during the five weeks was significantly greater than that of the controls, about 35 per cent greater. The number of leaves produced in set E was also larger than that of the controls. Aside from these factors, there were no other apparent differences between sets A and E—leaves were of approximately the same size and the numbers of flowers produced in both groups were about equal. There were no evidences of injury in any of the rayed plants. The results of this part of the experiment are shown in plate 3, fig. 2.

Tomatoes.—The tomatoes at the beginning of the experiment averaged about 2.5 cm. in height. The results of the experiment are shown in table IVa and IVb, and in plate 3, fig. 3.

Here, as in the cucumbers, there were no great differences among sets A, B, C and D, although in general the rayed sets showed slightly more growth than the controls, and furthermore the wet and dry weights and the dry percentages of wet weights were slightly greater in the rayed sets. In set E, the growth in height was very definitely greater, by approximately 35 per cent than in the controls. The number of leaves produced in set E was greater than that in set A, and the wet and dry weights and dry-weight percentage of wet were considerably larger. There were no signs of injury in the rayed plants.

In the tomatoes and cucumbers, the rayed sets showed a slightly greater dry-weight percentage and ash-weight percentage. Furthermore, in both plants in experiment II, growth was greater in all of the sets during the last 2½ weeks than during the first 2½. This would seem to indicate that the limit at which there would be repression of growth and injury by ultra-violet radiation had not been reached. The effects of passing that limit are shown by the results of experiment I.

TABLE IIIa

CUCUMBERS

Set	Average increase in height of plant and in number of leaves during experiment					
	1st 2½ weeks		2nd 2½ weeks		5 weeks—total	
	Height	Leaves	Height	Leaves	Height	Leaves
	cm.		cm.		cm.	
A	5.72	2.86	18.54	4.36	24.26	7.22
B	5.25	3.31	22.06	4.41	26.31	7.72
C	5.16	2.87	17.79	3.64	22.95	6.51
D	4.80	2.93	16.26	3.81	21.06	6.74
E	6.18	3.08	26.88	5.61	33.06	8.69

TABLE IIIb

CUCUMBERS

Set	Weights		
	Average wet weight	Average dry % of wet wt.	Average ash % of dry wt.
	gms.		
A	11.75	9.01	18.02
B	11.98	10.01	
C	11.92	9.92	
D	12.02	10.08	
E	14.16	9.98	20.29

TABLE IVa

TOMATOES

Set	Average increase in height of plant and in number of leaves during experiment					
	1st 2½ weeks		2nd 2½ weeks		5 weeks—total	
	Height	Leaves	Height	Leaves	Height	Leaves
	cm.		cm.		cm.	
A	5.91	4.50	13.97	.56	19.88	5.06
B	5.55	4.79	16.12	.80	21.72	5.59
C	5.17	4.62	18.00	1.00	23.17	4.72
D	4.90	3.99	16.81	1.61	21.71	5.60
E	5.67	3.92	21.23	2.19	26.90	6.11

TABLE IVb

TOMATOES

Set	Weights		
	Average wet weight	Average dry % of wet wt.	Average ash % of dry wt.
	gms.		
A	10.52	8.07	16.98
B	11.34	9.65	
C	13.06	9.77	
D	12.44	10.02	
E	15.18	10.45	19.15

Statistical analyses of the increases in length, the dry-weight percentages of wet weights, and the ash-weight percentages of dry weight were made. A $\frac{\text{mean difference}}{\text{probable error diff.}}$ of 4.00 is accepted as indicating complete reliability of results.[1] The values of the analyses are shown below:

[1] Garrett, H. E. Statistics in psychology and education. p. 136. London, 1926.

CUCUMBERS

Set	Height cm.	Dry % of wet wt.	Ash % of dry wt.
A/B	18.08	10.14	
A/C	32.82	7.03	
A/D	13.95	9.29	
A/E	54.03	13.65	9.18

TOMATOES

Set	Height cm.	Dry % of wet wt.	Ash % of dry wt.
A/B	5.50	5.01	
A/C	12.36	5.98	
A/D	9.34	9.76	
A/E	55.02	18.89	7.15

Discussion

The results of these experiments demonstrate that at least the longer ultra-violet wave lengths—those of the ultra-violet solar spectrum—produce accelerated growth in higher plants when applied in sufficient dosage. The results further show the lethal effects of the shorter wave lengths on the same plants.

Several interesting facts were brought out by the work. The greater stimulation at 100 inches as compared with that at 50 inches is in accord with earlier findings (Eltinge, '28), and may be attributed to the fact that at 50 inches some of the shorter rays, which may pass through the filter and which may be slightly repressive though not destructive to growth processes, reach the plants. At 100 inches, most of these short rays are screened out or are so diminished in intensity by the atmosphere of the increased distance through which they must pass that they exert none of their inhibitory effects. On the other hand, the differences in effects at the two distances may be merely a function of differences in amounts of radiation received, assuming a stimulatory limit, above which increased radiant energy produces only retardation of growth, or even pronounced injury. The radiation at 50 inches, even if qualitatively about the same as it is at 100 inches, is four times more intense than at 100 inches; hence it is logical to assume that if the radiation at 100 inches is of the proper intensity to induce a high degree of stimulation, the intensity at 50 inches, being, as it were, of four times greater energy value, closely approaches or surpasses slightly the limit of beneficial influences and produces less stimulation than at 100 inches, no stimulation at all, or at the other extreme, retardation.

The use of incremental and constant periods of radiation produced varied and somewhat uninterpretable results. In experiment I, the plants rayed with increments (B—screened, D—unscreened) showed better growth than those rayed for constant daily periods (C—screened, E—unscreened). In set B the growth rate was greater than that of the controls; in set C, the growth rate was less than those of the controls and of set B. At the end of the irradiation period, the plants in set D were taller and the leaves were slightly larger than those in set E; furthermore, the D plants lived a few days longer than did the E plants before succumbing to the lethal action of the ultra-violet radiation.

These differences cannot be accounted for on the basis of different amounts of energy received, since the periods were adjusted to insure equal energy values for all groups in the experiment. Hence the explanation seems to lie in the building up of a resistance in the plants rayed incrementally by means of a gradual increase in dosage, an "accustoming" process, as it were. Since the B plants showed more stimulation, the incremental process (when the lamp is screened) would seem to consist of two reactions: gradual adjustment of the plant to the radiation, followed by accelerated growth. When the lamp is unscreened, the incremental radiation reduces the injury to the plants. The failure of the constant-period method to induce more rapid growth in the case of the screened lamp may perhaps be due to the fact that without the adjustment process the dosage at the beginning is above the beneficial limit and hence only negative results occur.

The effect of the incremental method, on the other hand, might be explained upon this basis: that during the latter half of the five-weeks radiation period, the plants which were rayed by the incremental method were receiving considerably more energy per day than were those in the constant-period groups; this greater energy coming at a time when the growth rate was rapid may have caused the greater stimulation. This explanation seems to be invalidated, however, by the experiments in which the plants were rayed with the unscreened arc; here during the latter half of the five-weeks period, the plants in the incremental group were likewise receiving more energy per day than those in the constant-period group. If the above explanation were the true one, it would be expected that the plants in the incremental group would show the greater injury, but, as a matter of fact, the plants rayed incrementally showed *less* injury. This would seem to indicate that the resistance theory is more satisfactory.

The necessity of using an incremental method at 50 inches to produce any stimulation whatsoever might explain the negative results of Popp and Brown and of Newell and Arthur in their attempts to discover stimulation in the wave lengths above 300 mμ, since they both worked at distances of less than 50 inches—Popp and Brown at 50 cm., Newell and Arthur at 15 inches.

These explanations, however logically they coincide with the results of experiment I, are not wholly satisfactory when they are applied to experiment II. In the cucumber plants rayed through the quartz-lite filter, the incremental method induced greater growth than did the constant-period method. In all other rayed sets in experiment II, however, both in cucumbers and tomatoes, the reverse was true—the plants rayed incrementally showed less growth than those rayed for constant periods. An explanation of this is wanting. One possible cause—but hardly an important one—may be the fact that the plants used in experiment I were younger than those in experiment II, and that there may be different relations in the adjustment reactions of plants at different periods in their early development. Another suggestion to explain this variation is difference in wave length. In experiment I, where the increment sets showed the greater growth, the vita-glass filter was not used, but instead, the quartz-lite and the unscreened arc. In experiment II, in the cucumbers, the increment quartz-lite set showed greater growth than the constant-period quartz-lite set; in the tomatoes the reverse was true, but the difference was slight. In both tomatoes and cucumbers rayed through the vita-glass, however, the incremental method showed much less growth than the constant-period method. Hence, it appears as though the quality of the spectrum transmitted by the vita-glass might have caused this variation from conditions in experiment I.

It is interesting to note that not only the growth rates and numbers of leaves produced in rayed plants were greater than in the controls, but that also the dry-weight and ash-weight proportions were greater. The fact that the ash content of the rayed plants showed an increase over the controls is especially interesting, since ultra-violet radiation has been shown also to increase the mineral content, especially the calcium and phosphorus content, of animal tissues in the case of rickets and other deficiency diseases (Kramer and Boone, '22; Orr, Holt, Wilkins and Boone, '23; Ellis and Wells, '25). Beeskow ('27) reported that ultra-violet radiation increases the calcium and phosphorus content of soybeans which are exposed to a mercury arc.

Since greater stimulation occurred under the vita-glass filter than under the quartz-lite, it seems that wave-lengths between 313 mμ and 289 mμ are more potent in inducing growth than those longer than 313 mμ. It might be argued that the difference in stimulation produced by the two filters is a function of varying intensities of the radiation which they transmit; however, the intensity measurements show such slight differences that this argument is seemingly not valid. This agrees with the general findings concerning this shorter portion of the solar spectrum—its greater activity in photochemical processes, its greater efficiency in the treatment of rickets, etc.

Summary

1. The longer ultra-violet wave lengths under certain conditions described in this paper are stimulating to the growth of higher plants.

2. The injurious effects of the short wave lengths have been again demonstrated.

3. Dry weight and ash weight of plants employed in this work increase with ultra-violet treatment.

4. Wave lengths between 313 mμ and 289 mμ produce greater stimulation than those longer than 313 mμ.

5. The incremental method for the most part produces greater growth than the constant-period method, indicating an induced adjustment of the plants to the gradual increase of dosage.

6. The more marked stimulation occurs at a greater distance than that used by most other workers.

7. Statistical analyses proved the reliability of the results.

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EXPLANATION OF PLATE

PLATE 3

Fig. 1—Tomatoes—Exp. I

A—Control.
B—Rayed with quartz-lite filter by incremental method.
C—Rayed with quartz-lite filter by constant-period method.
D—Rayed with unscreened arc by incremental method.
E—Rayed with unscreened arc by constant-period method.

Fig. 2—Cucumbers—Exp. II

A—Control.
B—Rayed with quartz-lite filter by incremental method.
C—Rayed with quartz-lite filter by constant-period method.
D—Rayed with vita-glass filter by incremental method.
E—Rayed with vita-glass filter by constant-period method.

Fig. 3—Tomatoes—Exp. II

A—Control.
B—Rayed with quartz-lite filter by incremental method.
C—Rayed with quartz-lite filter by constant-period method.
D—Rayed with vita-glass filter by incremental method.
E—Rayed with vita-glass filter by constant-period method.